A classic proportional integral derivative (PID) architecture attitude-command/attitude-hold flight control system was used to stabilize the vehicle. Eleven design parameter gains in the control laws were initially set to values based on classical design methods. CONDUIT adjusts the design parameters to optimize the performance of the control laws against 21 design specifications. The final flight-control laws were optimized in CONDUIT just 5 days before the first flight. The final design represents a good balance between stability and performance without overdriving the actuators.

The first unmanned flight of this vehicle was flown on 12 January 2000—less than 4 months after the first frequency-sweep flight data were collected for mathematical model development. This first unmanned vehicle flight consisted of an 18-minute flight over a 2-mile course. The aircraft flew a simple four-sided racetrack pattern with a ground speed of 9 knots at an altitude of 100 feet above ground level (AGL). The flight was fully autonomous from engine startup to engine shutdown including an autonomous takeoff and landing. No buildup flights were flown prior to this autonomous flight, and the vehicle had no reversion mode for ground pilot control.

Although no open-loop control doublets were performed during the tests (stability augmentation system on at all times), several moderately abrupt control transitions were observed as part of normal flight. Comparison of the simulation models with the flight data shows an excellent agreement. Figure 2 shows a pitch input that was made into the inner-loop control laws during this flight. Feeding the control input signals into the simulation model produces the response shown by the dashed curve in figure 2. The quality of the agreement shows the value of using a good simulation model in the design of RUAVs. The vehicle flight-test performance and the agreement of the flight-test data with the simulation model indicated that no further improvements to the hover low-speed FCS design were warranted.

Northrop Grumman was awarded the contract on 8 February 2000 with immediate go-ahead. First flight of an EMD vehicle is scheduled for late 2001.

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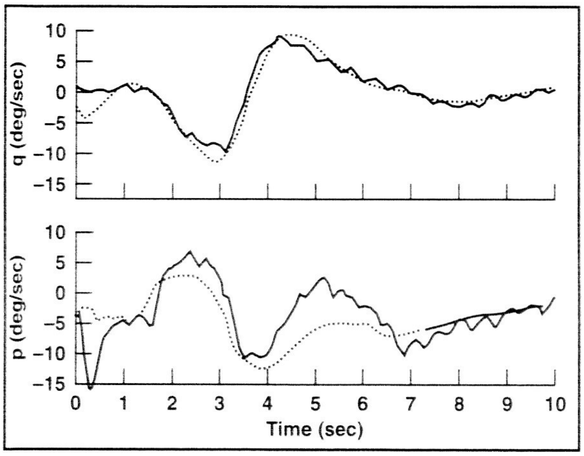

Fig. 2. Comparison of flight-test data to simulation model.

Vertical Lift Technology and NASA Revolutionary Concepts Program

Larry A. Young, John F. Madden, Khanh Q. Nguyen

Ames Research Center is a key team member on two NASA Revolutionary Concepts (REVCON) Phase I aeronautics projects, which focus on vertical lift technologies. The REVCON program is a Dryden Flight Research Center-led initiative that emphasizes the development and demonstration of high payoff aeronautics technologies that can be quickly taken from concept to flight. The REVCON projects are broken into two phases:

a Phase I $300,000, 8-month-long, system analysis and overall concept-feasibility assessment study, and a Phase II effort which encompasses the actual vehicle/technology development and flight demonstration. Contractors for both Phases are competitively selected. Only Phase I projects are considered for Phase II award. Proposals for the Phase I effort were solicited by means of a NASA Research Announcement (NRA).

One of the two vertical-lift technology projects that Ames is participating in is the Advanced Technology, Incorporated (ATI) Swashplateless Flight project (fig. 1). This project seeks to demonstrate, on an unmanned air vehicle (UAV), ultralight helicopter flight-test platform primary flight control (rotor blade pitch angle, collective, and cyclic) using embedded flaps on the rotor blades, driven by advanced electromagnetic actuators and power electronics. (Primary flight control for conventional rotorcraft is provided by a complex assembly of mechanical components which make up the rotor control system—the chief component of which is the swashplate.) These same rotor-blade electromagnetic actuators—in addition to providing primary flight control—will be used to demonstrate high frequency (greater than once-per-blade revolution) active rotor control for noise and vibration reduction. Successful demonstration of this technology could yield an elegant design approach for rotorcraft flight control that will reduce helicopter parasite drag, improve range and endurance, improve reliability and safety of operation, and at the same time reduce noise and vibration. The team members for the Swashplateless Flight project are ATI, Diversified Technologies Incorporated (DTI), Science Applications International Corp. (SAIC), the U.S. Army Aeroflightdynamics Directorate, the NASA Ames and Langley Research Centers, and the Dryden Flight Research Center.

The second vertical-lift REVCON project in which Ames is involved is Sikorsky Aircraft's

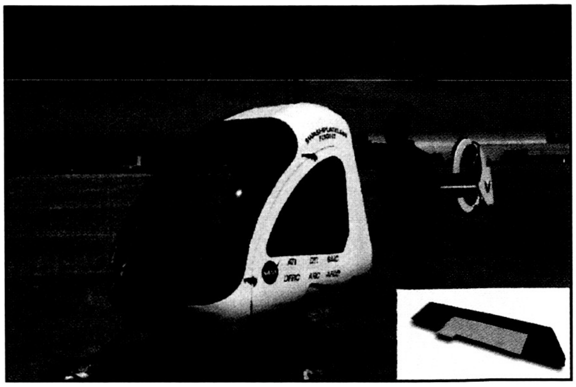

Fig. 1. ATI swashplateless flight project.

Variable-Diameter Tilt Rotor (VDTR) UAV demonstrator project (see fig. 2). The VDTR concept promises significant performance and safety advantages over conventional tilt rotors. The rotor blades of a VDTR aircraft telescope and retract radially along the blade span such that the rotors are at a larger diameter for hover and low-speed helicopter mode than they are in airplane-mode cruise. This rotor diameter change allows the VDTR aircraft to optimize its rotor disk loading and performance, for each flight condition. The comparatively lower VDTR rotor disk loading (compared with that of a conventional tilt-rotor aircraft) in low-speed helicopter mode allows for improved autorotation characteristics in case of an aircraft power loss. The team members for the VDTR project are Sikorsky, the U.S. Army Aeroflightdynamics Directorate, the NASA

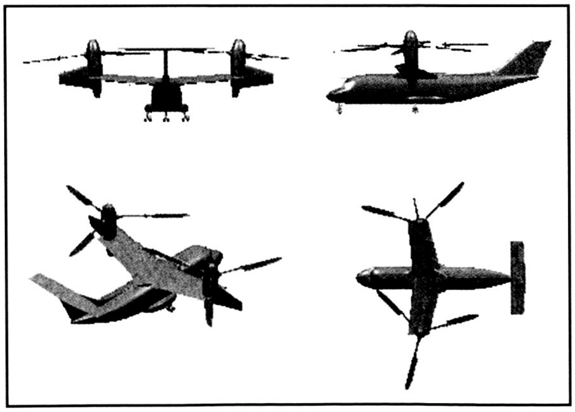

Fig. 2. Sikorsky Aircraft's Variable Diameter Tilt Rotor (VDTR) UAV Demonstrator Project.

Ames, Langley, and Glenn Research Centers, and the Dryden Flight Research Center.

Phase I work for both projects has been completed and final reports submitted. Selection and award of the REVCON Phase II projects will be made by the end of FY01.

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Mars Exploration Using Vertical-Lift Planetary Aerial Vehicles

Larry A. Young, Michael R. Derby, Edwin W. Aiken

Despite the thin, cold, carbon-dioxide-based atmosphere of Mars, recent work at Ames Research Center has suggested that vertical-lift planetary aerial vehicles (based on rotary-wing technology) could potentially be developed to support Mars exploration missions. The use of robotic vertical-lift planetary aerial vehicles would greatly augment the science-return potential of Mars exploration, but their development presents many technical challenges.

Why vertical-lift vehicles for planetary exploration? For the same reason that these vehicles provide such flexible aerial platforms for terrestrial exploration and transportation: their ability to hover and fly at low speeds and to take off and land at unprepared remote sites. Further, autonomous vertical-lift planetary aerial vehicles would have the following specific advantages and capabilities for planetary exploration:

- Hover and low-speed flight for aerial surveys
- Remote-site sample return to lander platforms, or precision placement of scientific probes
- Soft-landing capability for vehicle reuse and remote-site monitoring
- Greater range, speed, and access to hazardous terrain than a rover
- Better resolution of surface details than from an orbiter
- Could act as "astronaut agents"

Martian autonomous rotorcraft by their nature will have large lifting-surfaces and will be required to have ultralightweight construction. This in turn will pose a challenge in making them sufficiently robust to operate in the Martian environment. A number of vertical-lift aerial vehicle configurations for Mars exploration are being examined at Ames, including coaxial helicopters, quad-rotor helicopters, and tilt rotors (see fig. 1). Propulsion options include electric motors, powered by fuel cells or batteries, or an Akkerman hydrazine reciprocating engine.

Work to date has consisted mostly of conceptual design studies. NASA and Sikorsky Aircraft jointly sponsored the Year 2000 American Helicopter Society Student Design Competition for the design of a Martian autonomous rotorcraft. Excellent design proposals resulted from that competition. Many of the conclusions of the in-house work at Ames were supported by the independent design work done at the universities. Moreover, a considerable amount of enthusiasm was generated in academia and the industry for possible follow-on collaborative work.